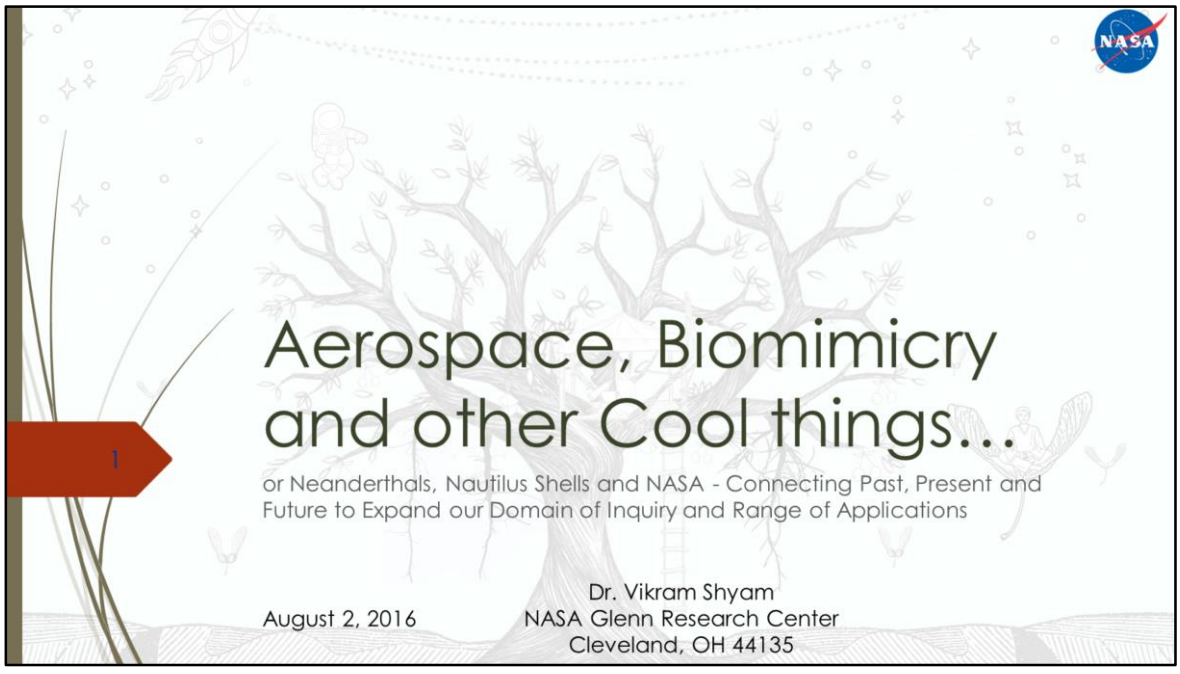
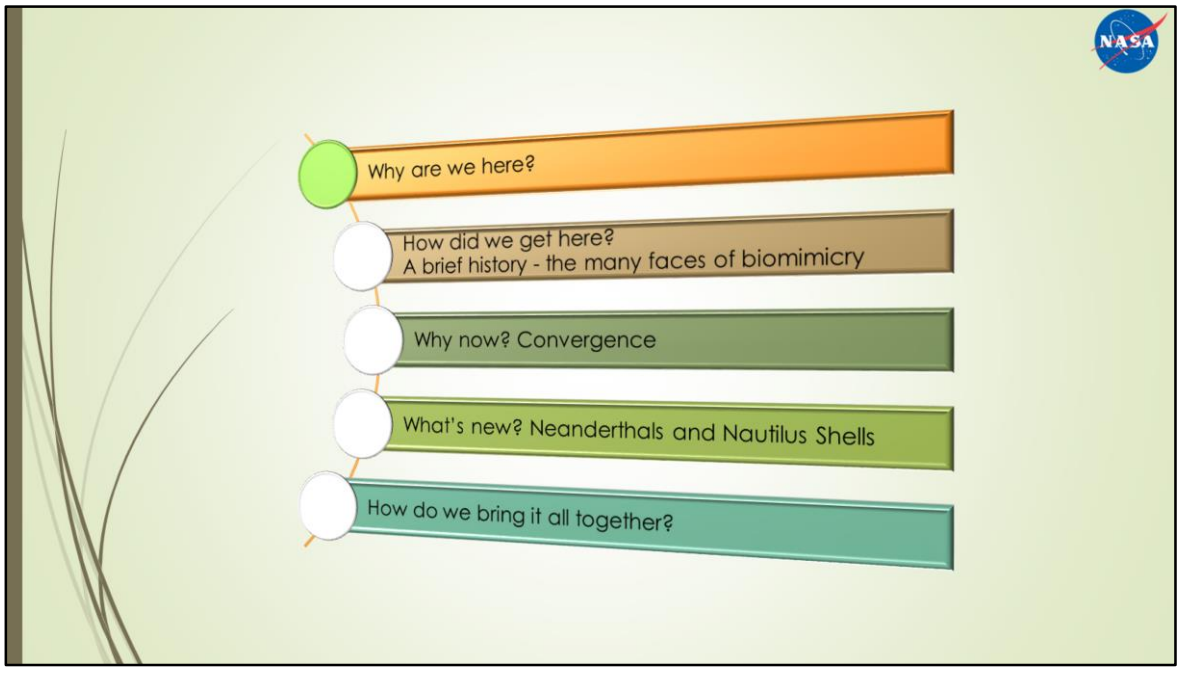

1
Aerospace, Biomimicry and other Cool things…
or Neanderthals, Nautilus Shells and NASA - Connecting Past, Present and Future to Expand our Domain of Inquiry and Range of Applications
August 2, 2016
Dr. Vikram Shyam
NASA Glenn Research Center
Cleveland, OH 44135


Why are we here?
How did we get here?
A brief history - the many faces of biomimicry
Why now? Convergence
What's new? Neanderthals and Nautilus Shells
How do we bring it all together?

/

Challenges – Acceptable Reasons*

- Resources
- Limits of knowledge

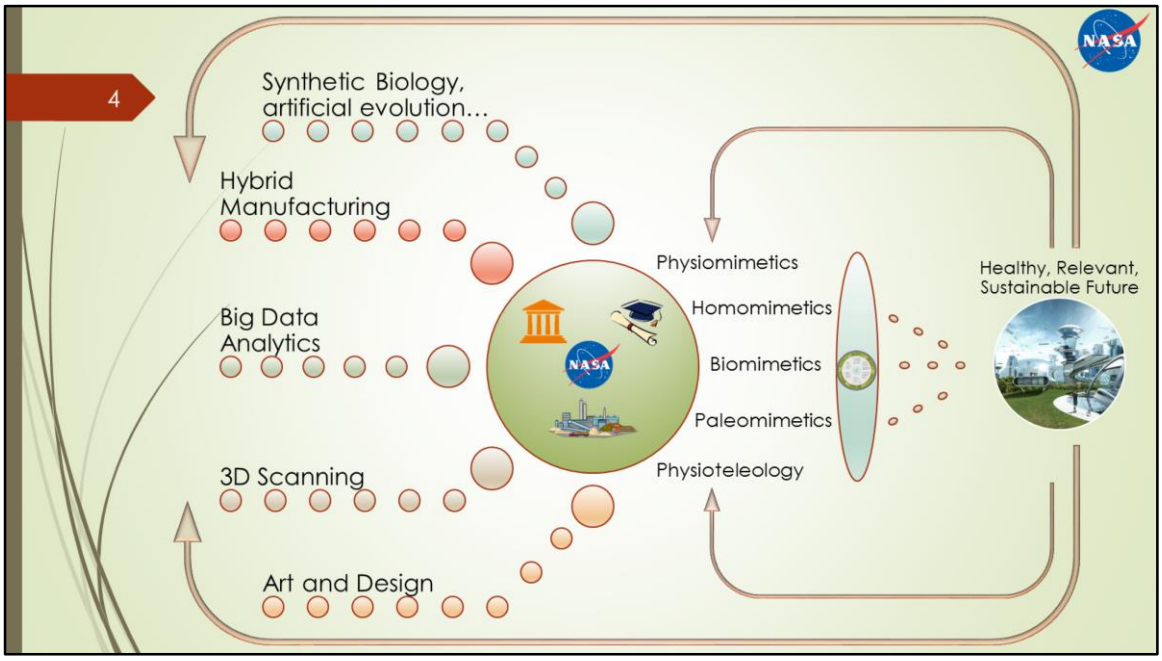
Opportunities – Real Reasons*

- Future scenarios
- New frontiers

Capabilities – We have the technology

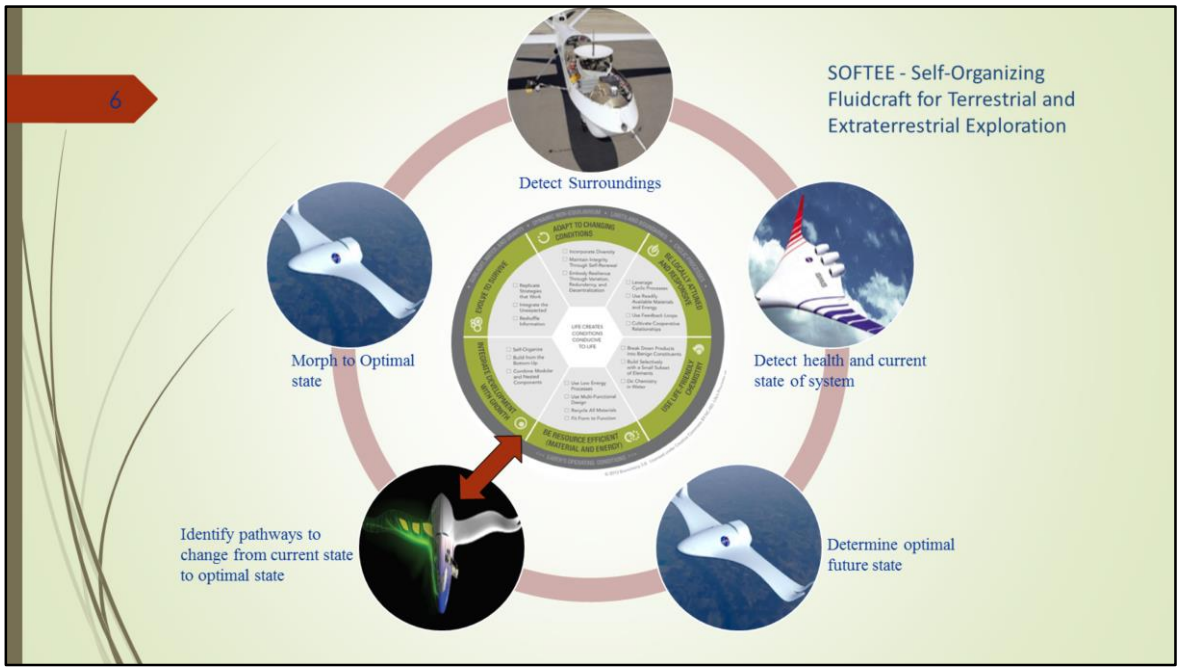
- People
- Philosophy
- Technology

*reference to speech by NASA administrator Mike Griffin



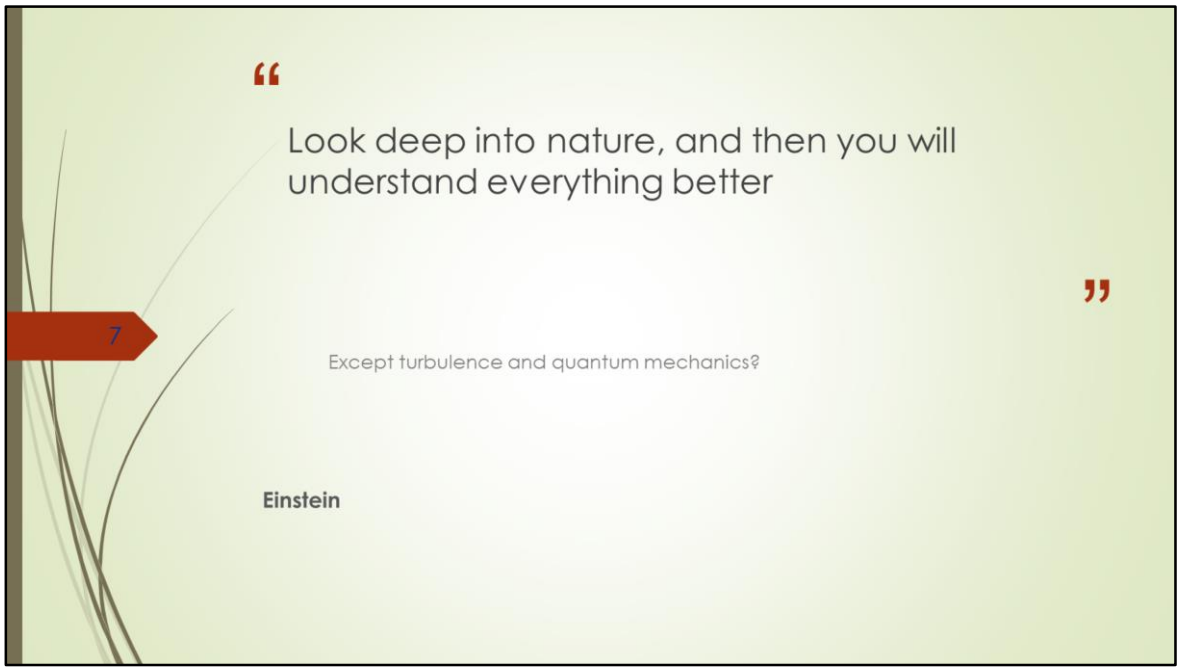
the condition that distinguishes animals and plants from inorganic matter, including the capacity for growth, reproduction, functional activity, and continual change preceding death

Synthetic biology - uses engineering principles to design and assemble biological components to create hybrid machine-living systems
Big data analytics – Harvest information from the patent and literature database to construct a periodic table of biology, sense everything, connect to everything and adapt in real-time
Additive manufacturing – the ability to replicate features and properties in nature
3D scanning – new capabilities allow us to examine and capture the essence of nature's every detail



A closed loop system informed by nature will sense its environment, draw on the periodic table of biology to identify an optimal configuration and morph to achieve the desired state.

This includes multi-scale and multi-level adjustments (mission level such as rotorcraft to fixed wing or flapping wing, system and subsystem level such as adjustments to wind gusts/ bird strikes, fouling).


“
Look deep into nature, and then you will understand everything better
”
7
Except turbulence and quantum mechanics?
Einstein

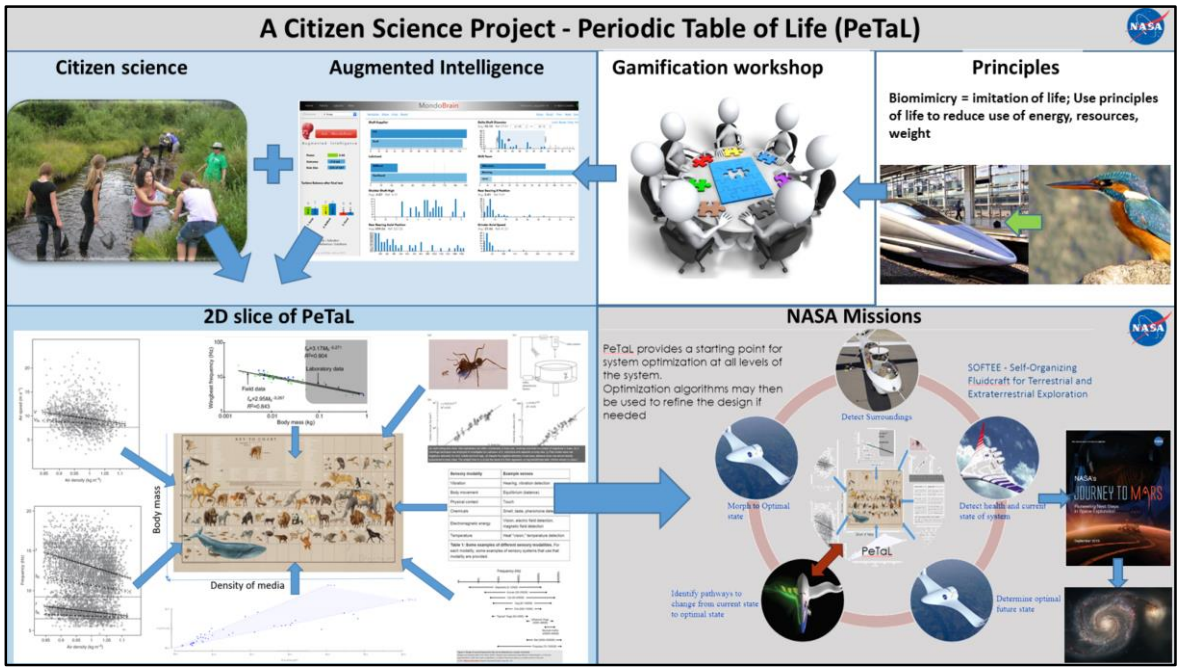
8

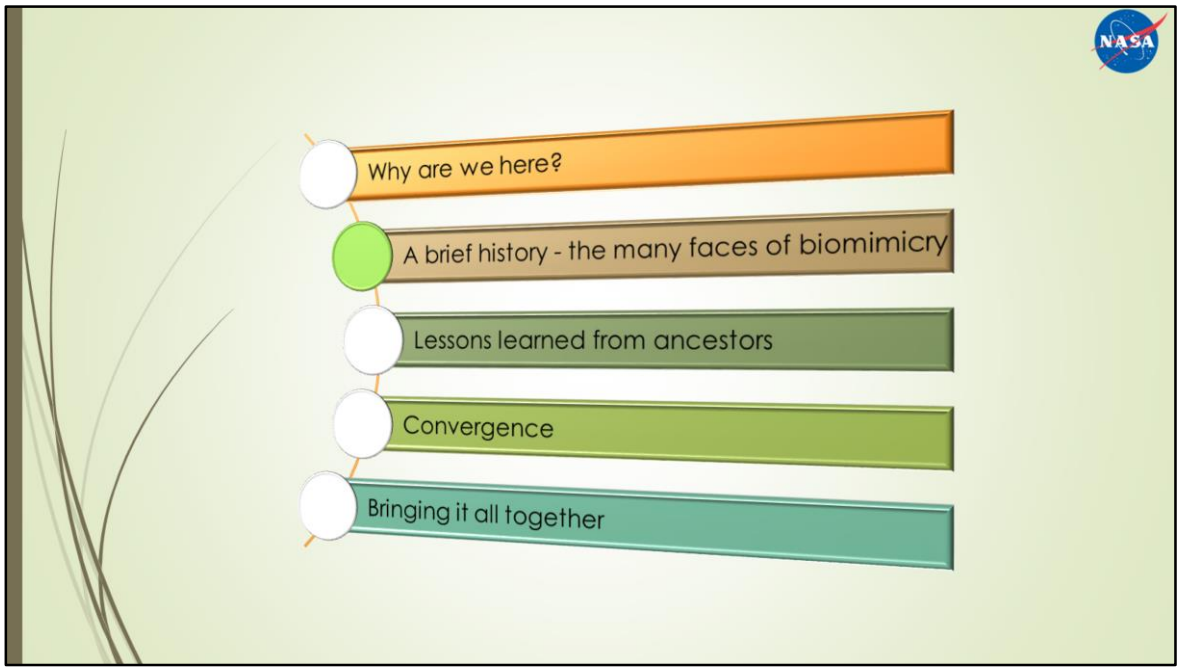
BioTRIZ

AskNature

Day 1: An Evolving Discipline
Day 2: Architecture, Art…
Day 3: Educational Aspects

PeTaL


A Citizen Science Project - Periodic Table of Life (PeTaL)
Citizen science
Augmented Intelligence
Gamification workshop
Principles
Biomimicry = imitation of life; Use principles of life to reduce use of energy, resources, weight
2D slice of PeTaL
Body mass
Density of media
NASA Missions
PeTaL provides a starting point for system optimization at all levels of the system.
Optimization algorithms may then be used to refine the design if needed
SOFTEE - Self-Organizing Fluidcraft for Terrestrial and Extraterrestrial Exploration
Detect Surroundings
Morph to Optimal state
Detect health and current state of system
PeTaL
Identify pathways to change from current state to optimal state
Determine optimal future state
JOURNEY TO MARS


Why are we here?
A brief history - the many faces of biomimicry
Lessons learned from ancestors
Convergence
Bringing it all together

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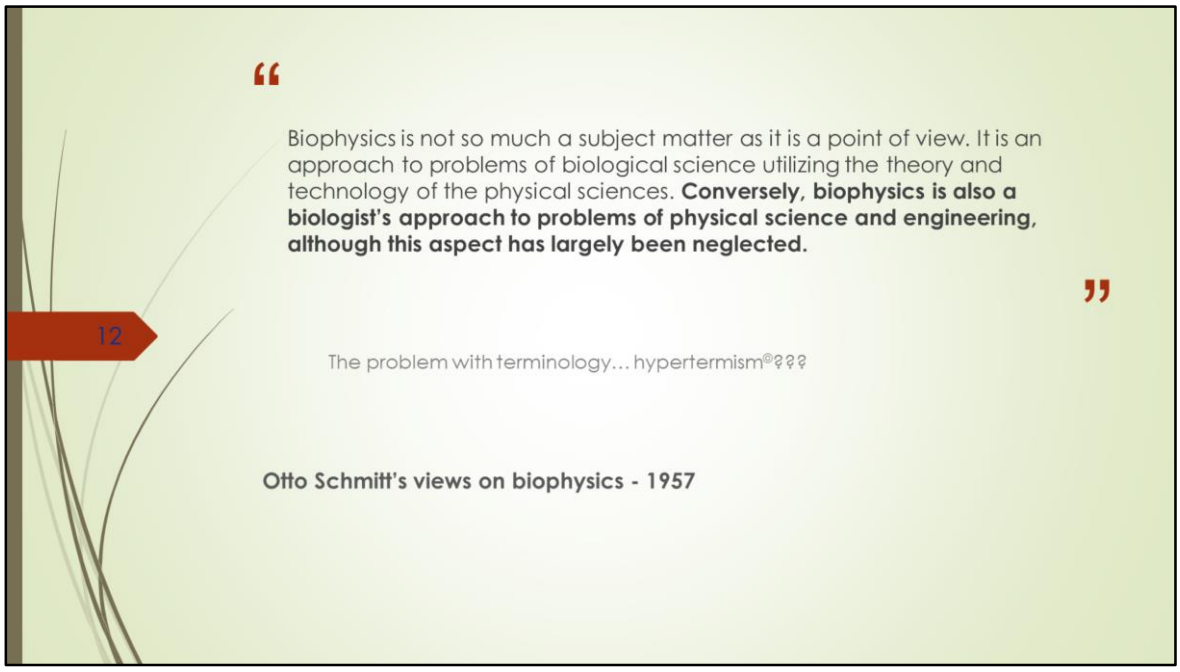
Biomimicry as defined by?

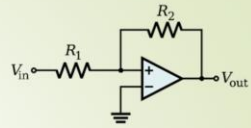
- Biophysics (Otto Schmitt, 1957)
- Bioengineering
- Biomechanics
- Biomedical engineering
- Bionics (like life) – Jack Steele (1960)
- Biomimesis, biomimicry (imitation of life)
  - Otto Schmitt (1960)
  - Janine Benyus (1999)
- Others???

"Terminology is the generalist's biggest enemy but is essential to accomplishing the generalist's goals"


“
Biophysics is not so much a subject matter as it is a point of view. It is an approach to problems of biological science utilizing the theory and technology of the physical sciences. **Conversely, biophysics is also a biologist's approach to problems of physical science and engineering, although this aspect has largely been neglected.**
”
12
The problem with terminology… hypertermism®???
Otto Schmitt's views on biophysics - 1957

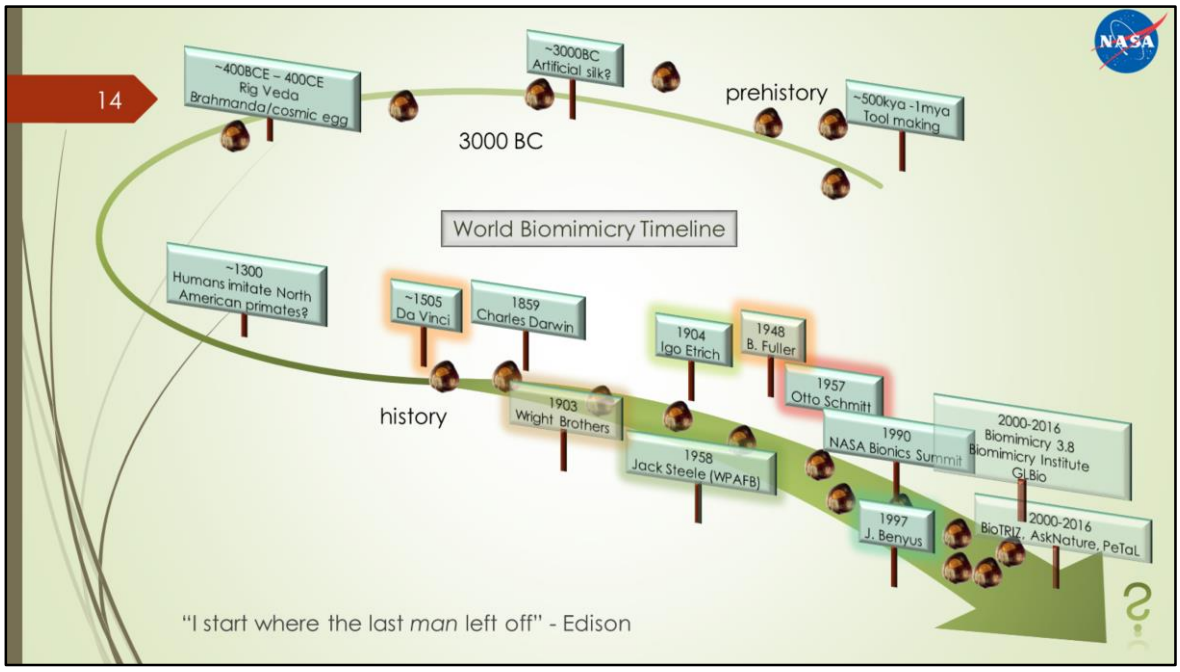
13

Otto Schmitt



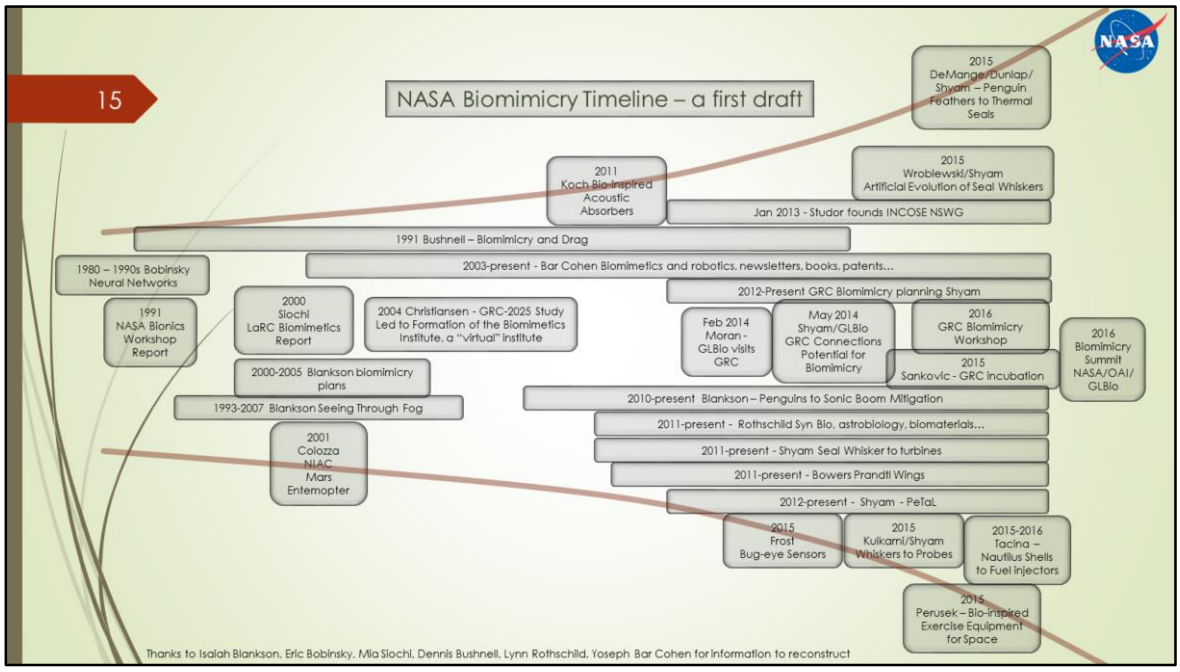
- Ph.D. with majors in Physics and Zoology, minor in mathematics
- Came up with 'biomimetics'
- Invented Schmitt trigger, cathode follower, differential amplifier…

"He didn't take the frog apart to find this out"

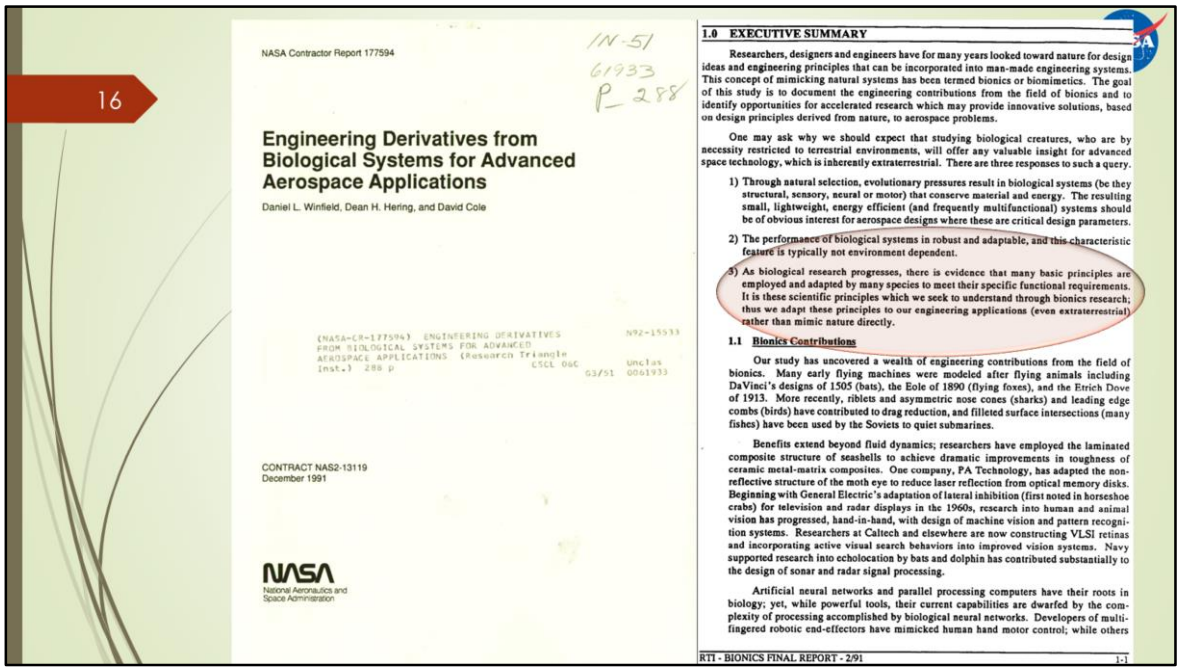


Many discoveries and philosophical contributions have led to the tools we have today. While Benyus' claim that Biomimicry is a new discipline is sometimes controversial, one must understand that there are two sides to this:

1. Biomimicry as a practice has been going on for a long time
2. Several proponents such as Fuller have suggested a systems approach
3. Benyus popularized and enabled a concerted effort thanks to IT, societal needs and emerging technologies like 3D printing, scanning etc. There has clearly been an uptick in biomimetic activity since her book and TED talk.



As an example, NASA has had a history in biomimicry. However, there have been many stops and starts and efforts to formalize and create a program did not succeed. Reasons being lack of external infrastructure, need for biomimicry not urgent, lack of communication technology (IT), budget cuts, lack of advocates.
Several names on timeline present at the summit.



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NASA Contractor Report 177594

IN-51
61933
P 288

Engineering Derivatives from Biological Systems for Advanced Aerospace Applications

Daniel L. Winfield, Dean H. Hering, and David Cole

(NASA-CR-177594) ENGINEERING DERIVATIVES FROM BIOLOGICAL SYSTEMS FOR ADVANCED AEROSPACE APPLICATIONS (Research Triangle Inst.) 288 p

N92-15533

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CSCL 06C
G3/51 0061933

CONTRACT NAS2-13119
December 1991

NASA
National Aeronautics and Space Administration

1.0 EXECUTIVE SUMMARY

Researchers, designers and engineers have for many years looked toward nature for design ideas and engineering principles that can be incorporated into man-made engineering systems. This concept of mimicking natural systems has been termed bionics or biomimetics. The goal of this study is to document the engineering contributions from the field of bionics and to identify opportunities for accelerated research which may provide innovative solutions, based on design principles derived from nature, to aerospace problems.

One may ask why we should expect that studying biological creatures, who are by necessity restricted to terrestrial environments, will offer any valuable insight for advanced space technology, which is inherently extraterrestrial. There are three responses to such a query.

1) Through natural selection, evolutionary pressures result in biological systems (be they structural, sensory, neural or motor) that conserve material and energy. The resulting small, lightweight, energy efficient (and frequently multifunctional) systems should be of obvious interest for aerospace designs where these are critical design parameters.

2) The performance of biological systems in robust and adaptable, and this characteristic feature is typically not environment dependent.

3) As biological research progresses, there is evidence that many basic principles are employed and adapted by many species to meet their specific functional requirements. It is these scientific principles which we seek to understand through bionics research; thus we adapt these principles to our engineering applications (even extraterrestrial) rather than mimic nature directly.

1.1 Bionics Contributions

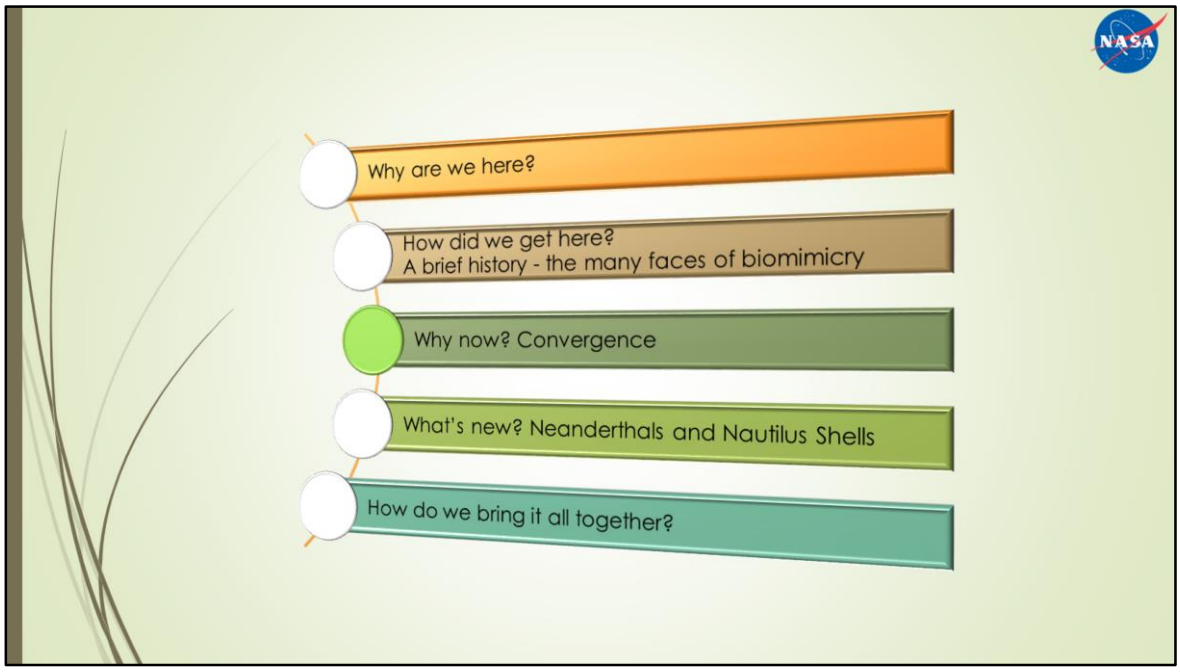
Our study has uncovered a wealth of engineering contributions from the field of bionics. Many early flying machines were modeled after flying animals including DaVinci's designs of 1505 (bats), the Eole of 1890 (flying foxes), and the Etrich Dove of 1913. More recently, riblets and asymmetric nose cones (sharks) and leading edge combs (birds) have contributed to drag reduction, and filleted surface intersections (many fishes) have been used by the Soviets to quiet submarines.

Benefits extend beyond fluid dynamics; researchers have employed the laminated composite structure of seashells to achieve dramatic improvements in toughness of ceramic metal-matrix composites. One company, PA Technology, has adapted the non-reflective structure of the moth eye to reduce laser reflection from optical memory disks. Beginning with General Electric's adaptation of lateral inhibition (first noted in horseshoe crabs) for television and radar displays in the 1960s, research into human and animal vision has progressed, hand-in-hand, with design of machine vision and pattern recognition systems. Researchers at Caltech and elsewhere are now constructing VLSI retinas and incorporating active visual search behaviors into improved vision systems. Navy supported research into echolocation by bats and dolphin has contributed substantially to the design of sonar and radar signal processing.

Artificial neural networks and parallel processing computers have their roots in biology; yet, while powerful tools, their current capabilities are dwarfed by the complexity of processing accomplished by biological neural networks. Developers of multi-fingered robotic end-effectors have mimicked human hand motor control; while others

RTI - BIONICS FINAL REPORT - 2/91 1-1

Clearly more biomimetic examples before 1990 at NASA and other government agencies.
The language already implies that functional principles should be understood and not superficial mimicry.
A database is suggested to aid in design.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/

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Patterns and optimality

Sunflower seeds

Nautilus shell

$$r = ae^{b\theta}$$

Whirlpool galaxy

Romanesco broccoli

By NASA and European Space Agency - http://antwrp.gsfc.nasa.gov/apod/ap050428.html SOURCE OF 2ND VERSION: http://www.spacetelescope.org/images/html/heic0506a.html also bigger versions up to about 12000x8000 pixel available, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3863746

By Jon Sullivan - http://pdphoto.org/PictureDetail.php?mat=pdef&pg=8232, Public Domain, https://commons.wikimedia.org/w/index.php?curid=95997

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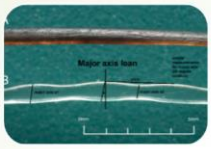
Patterns and optimality



Seal whiskers

Whale fins

Meat eater ant

Cactus

By Taken byflr0002 | flagstaffotos.com.auCanon 20D + Sigma 150mm f/2.8 - Own work, GFDL 1.2, https://commons.wikimedia.org/w/index.php?curid=1499681

20

Patterns and convergence

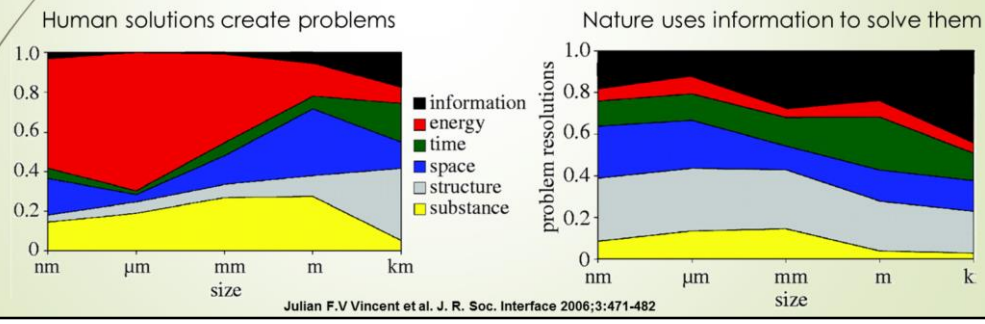
- These patterns exist even in human interactions
- Big ideas take time to develop. During this time there is division (think flat earth vs round earth)
- Generalists and specialists? Collective learning always feeds into formation of philosophy that tries to unify more and more of our collective learning through space and time.

Political will
Agreement on ideas
Economic incentives
Challenges
Big ideas or unifying theories
Frustration/happiness
Productivity
…

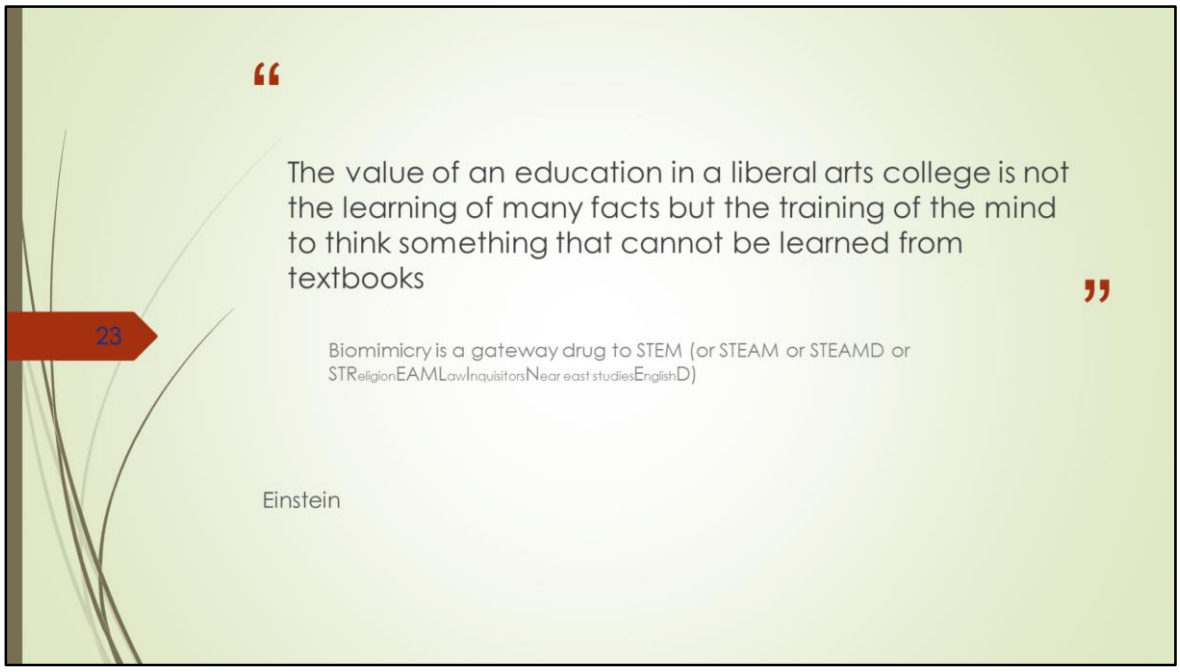
Time

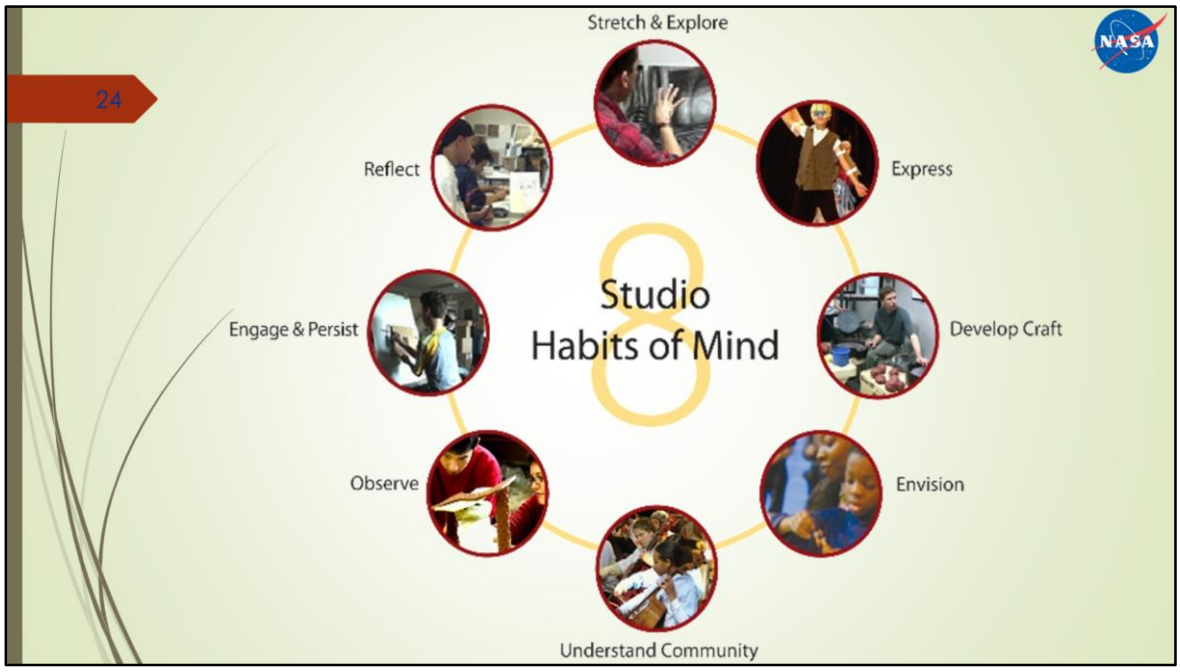
22

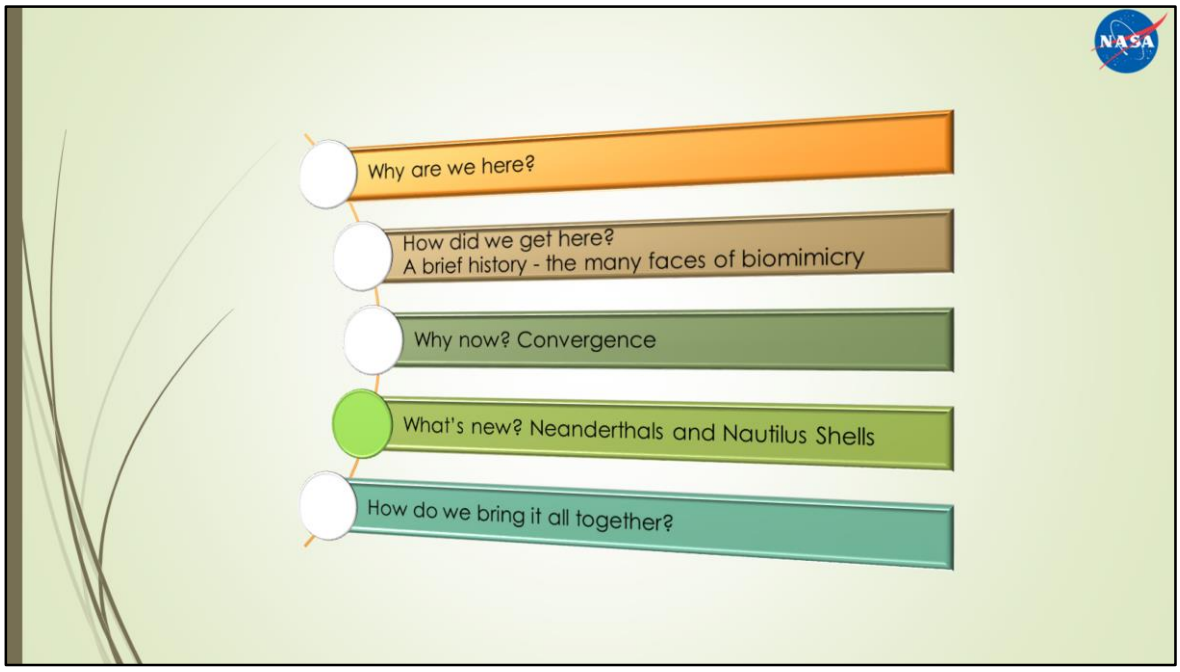
The information age meets design by information



Julian F.V Vincent et al. J. R. Soc. Interface 2006;3:471-482


“
The value of an education in a liberal arts college is not the learning of many facts but the training of the mind to think something that cannot be learned from textbooks
”
23
Biomimicry is a gateway drug to STEM (or STEAM or STEAMD or STReligionEAMLawInquisitorsNear east studiesEnglishD)
Einstein


Stretch & Explore
Express
Develop Craft
Envision
Understand Community
Observe
Engage & Persist
Reflect
8
Studio
Habits of Mind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MESOZOIC ERA
JURASSIC PERIOD
CRETACEOUS PERIOD
CAMBRIAN PERIOD
ORDOVICIAN PERIOD
PERMIAN PERIOD
PENNSYLVANIAN PERIOD
MISSISSIPPIAN PERIOD
DEVONIAN PERIOD
PRECAMBRIAN
CENOZOIC ERA
Pliocene Epoch
Miocene Epoch
Holocene Epoch
Pleistocene Epoch
QUATERNARY PERIOD
TERTIARY PERIOD

27

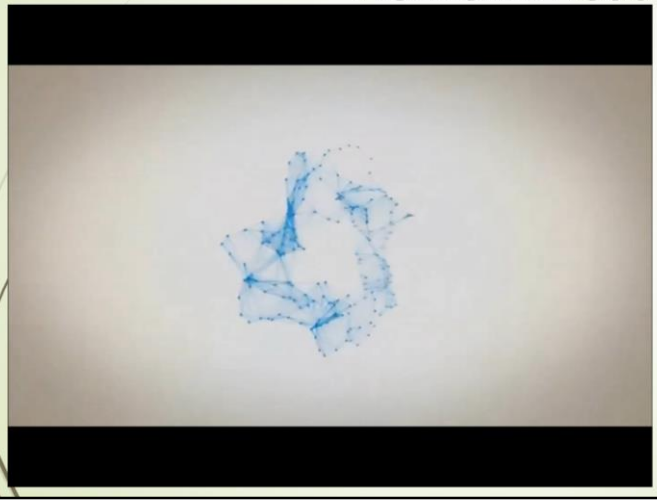
What can we learn from Pterosaurs?
Paleomimesis

Kingdom:	Animalia
Phylum:	Chordata
Clade:	Ornithodira
Clade:	†**Pterosauromorpha** Padian, 1997
Order:	†**Pterosauria** Kaup, 1834

Day 2: Harvey Webster
Day 2: Evening session

28

What can we learn from ancient humans?
Homomimesis



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Artificial Evolution

By AndrewHorne - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=13159244

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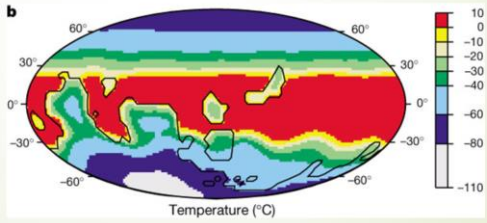
Why connect past and present?

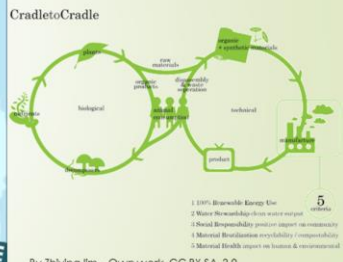
- Past may offer insights into extraterrestrial climes/life
- NASA GEER facility – simulate past, predict future?
- Learn from behavioral response to extinction, climate change
- Learn from mistakes when we scatter to the stars…



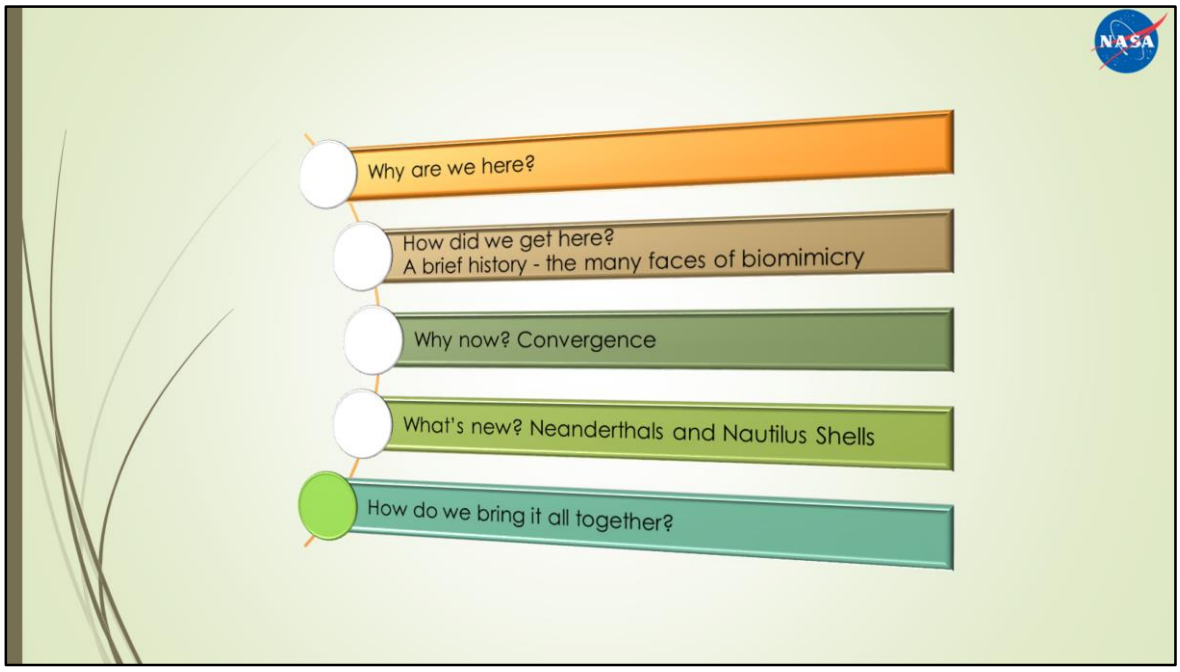
Kenneth H. Nealson, Joseph L. Kirschvink, Eric J. Gaidos, *Life in Ice-Covered Oceans*, PERSPECTIVES: BIOGEOCHEMISTRY, 1999,

31

Natural systems - *Physiomimesis*



By Zhiying.lim - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21082299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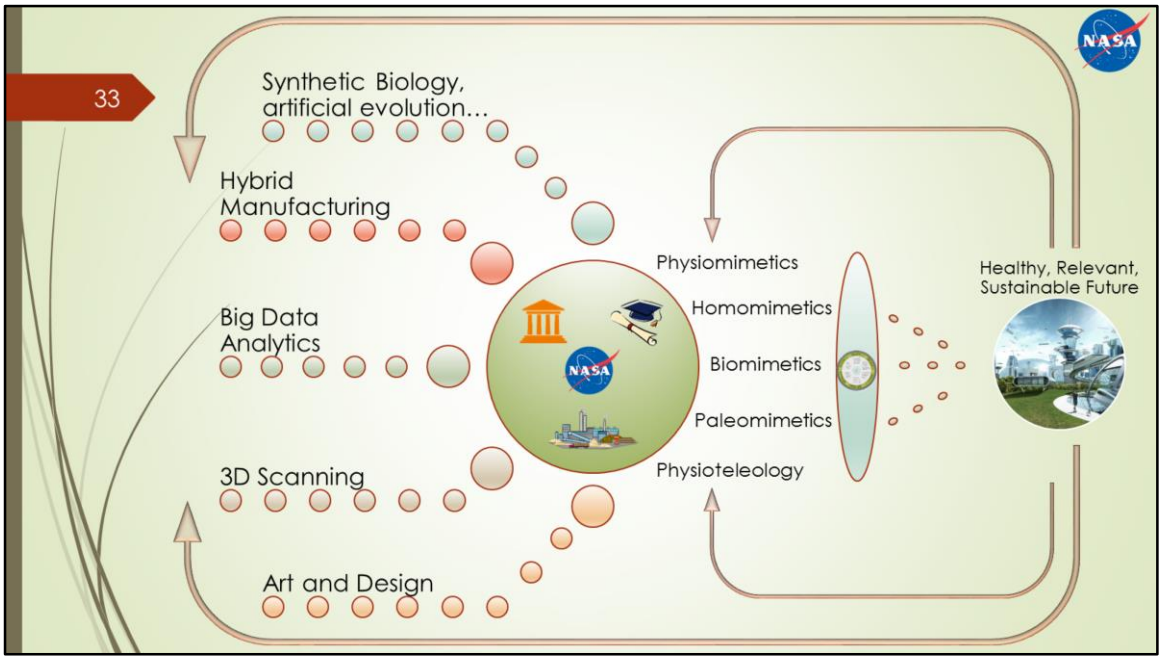

the condition that distinguishes animals and plants from inorganic matter, including the capacity for growth, reproduction, functional activity, and continual change preceding death

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Additive manufacturing – the ability to replicate features and properties in nature
3D scanning – new capabilities allow us to examine and capture the essence of nature's every detail

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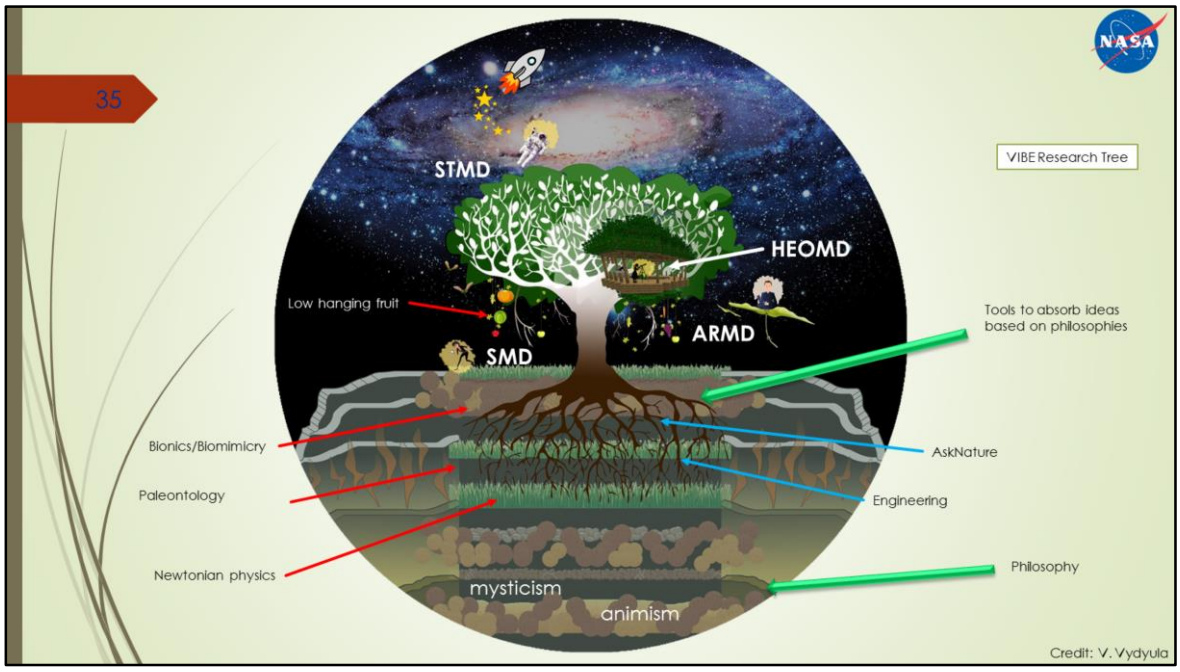
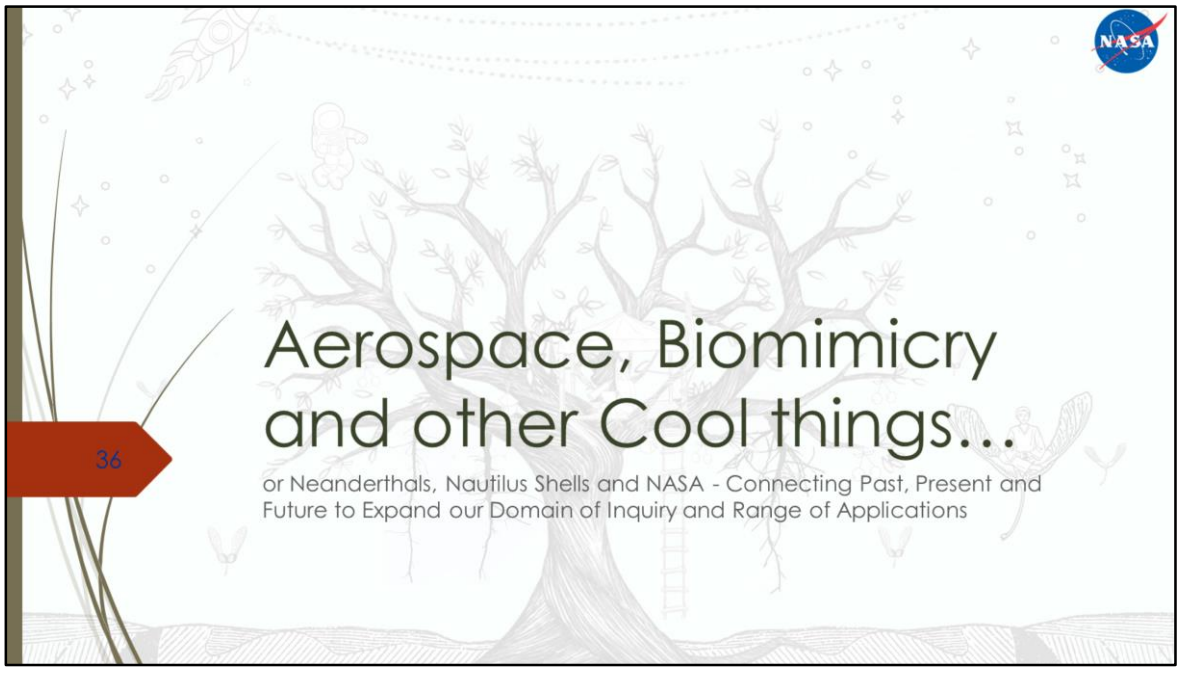
Summit Objectives…

- Establish a convergence of practitioners, disciplines, bio-inspired philosophy, tools, and research to benefit NASA, the nation and planet
- **Collaboration session – August 4, 2016, 2pm-5pm**
  - Develop framework for collaboration - NASA VIBE (Virtual Institute for Bio-inspired Exploration)
  - VIBE's vision - sustainable NASA biomimicry program
  - Formation of an advisory council
  - White papers
  - Best practices (and ethics)

Nature-inspired Exploration on Earth and In Space For the Benefit of All Life


35
VIBE Research Tree
STMD
HEOMD
Low hanging fruit
ARMD
SMD
Tools to absorb ideas based on philosophies
Bionics/Biomimicry
AskNature
Paleontology
Engineering
Newtonian physics
Philosophy
mysticism
animism
Credit: V. Vydyula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Aerospace, Biomimicry and other Cool things…
or Neanderthals, Nautilus Shells and NASA - Connecting Past, Present and Future to Expand our Domain of Inquiry and Range of Applications

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Acknowledgements

- Isaiah Blankson – Senior Technologist, propulsion/GRC
- Eric Bobinsky – Terasphere
- Dennis Bushnell – Chief Scientist, LaRc
- Virtual Institute for Bio-inspired Exploration (VIBE) team – https://www.grc.nasa.gov/vibe
- NASA GRC Senior Leadership
- NASA Office of Chief Scientist and Senior Leadership
- NASA ARMD Senior Leadership
- Varsha Vydyula – Aham Foundation